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Longshore Currents and Sediment Transport along Kannirajapuram Coast, Tamilnadu, India

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ABSTRACT

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The objective of the study was to estimate longshore current and sediment transport from measured wave data and from the observations on the littoral environment. A directional wave rider buoy was deployed at 12m water depth, 11 km off Kannirajapuram. Wave data at 3 hourly intervals from March 1997 to February 1998 were recorded. The first wave direction corresponding to the peak of the spectrum and second wave direction corresponding to the secondary peak were estimated since wave spectrum at this location was mainly double peak spectrum. Daily observations on surf zone width and longshore currents were carried out at Kannirajapuram beach during March 1997 to February 1998. The longshore currents and sediment transport were estimated considering first and second breaker angles and resultant was estimated considering the ratio of the first and second spectral energy peaks. Comparison of measured and computed longshore current shows that currents can be reasonably well estimated based on Galvin's equation and sediment transport based on Walton's equation.

ADDITIONAL INDEX WORDS: *Littoral drift, Indian coast, littoral environmental parameters.*

INTRODUCTION

The objective of the study was to estimate longshore current and sediment transport from measured wave data and from observations on the littoral environment. Longshore currents are generated due to waves breaking at an angle to the shoreline. The shape of coastline, beach face slope, nearshore profile, and presence of sand bars and shoals significantly influence the distribution of longshore currents.

The study region is situated along the southwest coast of India in Gulf of Mannar as indicated in Figure 1. The region around Kannirajapuram consists of 16–25 km wide coastal plain composed of recent alluvium. Further inside the coast charnockites and khondalites are present. Low tidal flats fed with tidal creeks and sandy plain extend nearly 5 km inside the coast. River Vaippar joins Gulf of Mannar about 15 km south of the study region. Gundar river and a large tidal creek join the Gulf of Mannar form a backwater system. A small creek connected to this backwater system joins the sea near Vembar. This creek is open and connected to sea during the northeast monsoon months and closed by sand spit during the rest of the year due to negligible fresh water discharge. There are many small and large salt pans spread along the coastline in this region. Beaches are composed of fine sand, and they are low and narrow with 100–150 m width. Nearshore is shallow with 5 m contour occurring at 0.6 km distance and 10 m contour occurring at 8.5 km distance from the shoreline. The nearshore on the southern and northern side of the study region is fringed with reef patches.

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Abundant growth of corals, oysters, sponges and other bottom communities flourish in the relatively calm water of Gulf of Mannar. The oceanography of this region is controlled by three different seasons *viz.,* i) southwest monsoon (June to September), ii) northeast monsoon (October to January) and iii) fair weather period (February to May). Most of the storms/cyclones are confined to the northern part of the Tamilnadu coast. Only 9 cyclonic disturbances have been reported or recorded in this region during 1891 to 1970. Table 1 gives the frequency of occurrence of storms within the vicinity of 250 km off Kannirajapuram during 1891–1970. Tides in this region are characterized by a mixed type of predominantly semi-diurnal. The predicted tides for Tuticorin 50 km south off Kannirajapuram shows that the average spring tidal range is about 0.7 m and the average neap tidal range is about 0.16 m. The rainfall is low about 160 cm in a year and mostly precipitation occurs during November to February. The summer lasts from March to July when the climate is very hot.

The pattern of longshore sediment transport in this region has not yet been investigated in detail due to non availability of data on waves and longshore currents. Earlier works were mostly based on historical ship reports on waves and dredging records (SAXENA *et al.* 1976, CHANDRAMOHAN *et al.* 1990). The factual assessment on sediment transport along this coastline is vital since it adjoins the sheltered Gulf of Mannar. Any depletion of the supply of littoral sediment to this segment would invariably affect the stability of this coast. In the present study, waves were measured off Kannirajapuram for a period of one year and used to estimate the

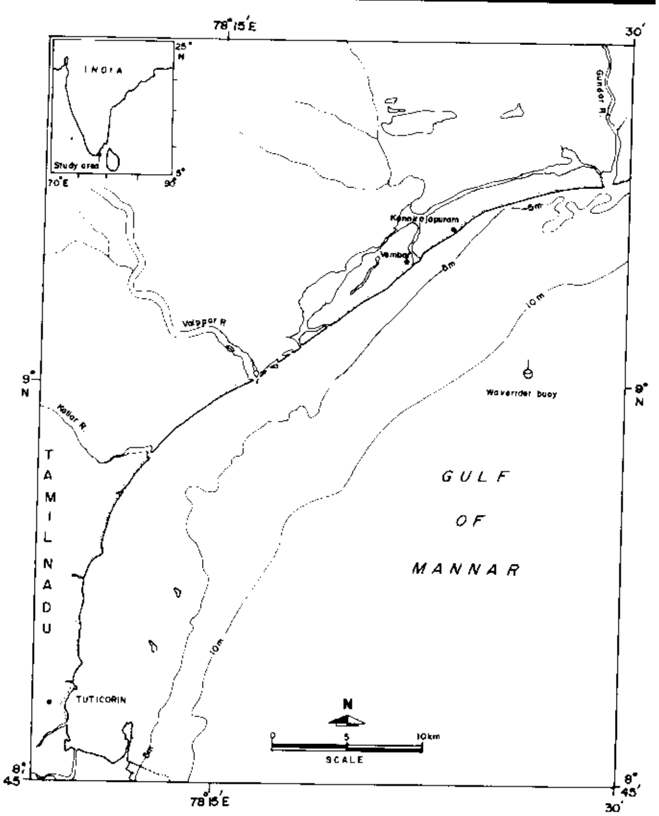

Figure 1. Study area.

longshore currents and longshore sediment transport rate considering the wave directions corresponding to first and second spectral peak. Daily littoral environmental parameters (SCHNEIDER, 1981) were also observed at Kannirajapuram beach and the longshore sediment transport was estimated. A comparative study was carried out on theoretical longshore currents and measured longshore currents.

METHODS AND ANALYSIS

Waves

A Datawell directional waverider buoy was deployed at 12 m water depth, at a distance of 11 km off Kannirajapuram and the data were recorded for 20 minutes duration, at every 3 hourly interval from March 1997 to February 1998. The significant wave height (H_s), zero crossing wave period (T_z) and first wave direction (with respect to north) corresponding to the peak of the spectrum (maximum spectral energy) and second wave direction corresponding to the secondary peak were estimated. This has become necessary because the wave spectrum at this location is mainly double-peaked. The ratio of the wave energy at the first and second peak were also estimated. It is to be noted that in many cases the wave direction is considered as the direction corresponding to the maximum spectral energy (KUIK *et al.*, 1988).

Table 1. *Frequency of occurrence of storms within the vicinity of 250 km off Kannirajapuram during 1891–1970.*

Month	Frequency
January	1
February	—
March	1
April	—
May	—
June	—
July	—
August	—
September	—
October	1
November	3
December	3

Breaking Wave Characteristics

The wave height and direction measured at 12 m water depth were reduced to wave breaking zone (SKOVGAARD *et al.*, 1975). The wave shoaling coefficients were estimated using small amplitude wave theory. As the contours are straight and parallel, the wave directions measured at 12 m water depth were corrected to refraction effects using Snell's law and the breaker angles corresponding to the first and second wave direction were calculated.

Surf Zone Characteristics

Daily observation on breaking wave height, surf zone width and longshore currents were carried out at Kannirajapuram beach during March 1997 to February 1998 while standing on the coastline close to the waterline. Magnitude and direction of the longshore currents were measured using Rhodamine-B dye in the surfzone. The distance covered in 2 minutes was measured and the average longshore current was estimated.

Theoretical Longshore Currents

Two commonly used equations to estimate the longshore current are given by:

(i) GALVIN (1963)

$$V_G = Kgm\ T \sin 2\alpha_b \tag{1}$$

(ii) LONGUET-HIGGINS (1970)

$$V_{L\text{-}H} = 20.7\ m\ (gH_b)^{1/2} \sin 2\alpha_b \tag{2}$$

where, V_G and $V_{L\text{-}H}$ are the mean longshore current velocity over the surf zone in m/s, K is a dimensionless coefficient depending solely on the geometry of the breaking wave which is taken as 1 (GALVIN, 1987), g is acceleration of gravity in m/s², m is the foreshore slope, T is the wave period in s, H_b the breaking wave height in m and α_b is the breaker angle (Angle between the breaking wave crest and the shoreline). The longshore currents were estimated considering the first and second breaker angles and the resultant was estimated considering the ratio of the first and second peak spectral energy.

Table 2. *Ranges of measured wave characteristics at 12 m water depth.*

Month	Hs (m)	Hmax (m)	Tz (s)	Tp (s)	θ_1 (deg)	θ_2 (deg)
Mar 97	0.46–1.12	0.67–1.78	3.2–7.4	3.6–14.3	84–202	81–202
Apr 97	0.33–1.18	0.44–1.73	3.2–6.3	3.1–18.2	91–192	85–201
May 97	0.46–1.93	0.66–2.81	3.5–9.3	3.8–20.0	138–197	115–194
Jun 97	0.64–1.87	0.87–2.72	3.7–7.3	4.5–18.2	145–198	148–236
Jul 97	0.66–1.60	0.91–2.45	3.8–8.5	4.2–18.2	139–229	145–245
Aug 97	0.59–1.49	0.89–2.48	3.7–8.2	3.4–18.2	141–231	150–235
Sep 97	0.64–1.76	0.88–2.96	3.7–8.5	3.8–18.2	143–206	146–247
Oct 97	0.50–1.35	0.66–2.94	3.4–8.7	4.0–18.2	125–196	92–202
Nov 97	0.40–1.13	0.59–1.65	2.9–8.3	3.2–16.7	84–183	5–350
Dec 97	0.38–1.12	0.48–1.73	2.7–7.5	3.5–18.2	94–187	4–184
Jan 98	0.37–1.03	0.47–1.68	2.8–6.6	2.9–15.4	38–188	2–357
Feb 98	0.35–1.23	0.45–1.79	2.8–7.4	2.6–16.7	17–200	14–352

Longshore Sediment Transport.

The longshore transport rate is usually estimated from an empirical equation relating the longshore energy flux in the breaker zone to the longshore transport rate. Several discussions have already appeared on the selection of suitable equations for estimation of the longshore sediment transport (GRAFF and OVEREEM 1979, WILLIS 1980). CHANDRAMOHAN *et al.* (1988) discussed the suitability of the SHORE PROTECTION MANUAL (1984) equation for estimating the longshore transport rate for the Indian coast. As per the SPM, the longshore transport rate, Q is given by,

$$Q = 1290\frac{\rho g^2}{64\pi}TH_b{}^2\sin 2\alpha_b \tag{3}$$

where Q = volume of longshore transport in m³/year and ρ = mass density of sea water in kg/m³.

Using the daily observed littoral environmental parameters, longshore sediment transport rate was estimated using Walton's equation (WALTON and BRUNO, 1989):

$$Q = \frac{1290\rho g H_b w v C_f}{0.78\left(\frac{5\pi}{2}\right)\left(\frac{v}{v_0}\right)} \tag{4}$$

where C_f = the friction coefficient (= 0.01), w = surf zone width in m, v = measured longshore current velocity in m/s and (v/v_0) = theoretical dimensionless longshore current velocity (LONGUET-HIGGINS, 1970).

The measured data on waves were used for estimating longshore sediment transport using eqn. (3) and the daily observed littoral environmental parameters were used to estimate the longshore sediment transport using eqn. (4).

RESULTS AND DISCUSSION

Measured Waves

Based on the analysis of the wave records, the ranges of predominant wave characteristics in different months are shown in Table 2. The wave heights were relatively high during May, June and September. The highest significant wave height (Hs) of 1.93 m was observed in May 1997 and the highest maximum wave height (Hmax) of 2.96 m was observed in September 1997 during the study period. The zero crossing wave period (Tz) varied between 3 and 9 s. The wave direction at spectral peak (θ_1) varied from 90 to 200° during March and April, from 140 to 200° during May, June and September and from 140 to 230° during July and August. The variation of wave direction estimated at first spectral peak (θ_1) and second spectral peak (θ_2) is shown in Figure 2(A). It shows that even though the ranges of wave direction at first spectral peak and second spectral peak are almost same, the variation between these two are more in July, August and November to January compared to other months. The corresponding breaker angle estimated is shown in Figure 2(B). The breaker angle for the waves approaching the coast from southwesterly are considered negative and that for waves approaching the coast from northeasterly are considered positive. The figure shows that breaking waves were mainly from southwesterly direction during March to November. The ratio of spectral energy at first and second spectral peak is shown in Figure 2(C). It shows that the energy at second peak is more than 50% of the energy at first peak in 57% of the data collected. So it is important to consider both directions for this location.

Surf Zone Characteristics

The daily variation of breaking significant wave height (H_b) and zero crossing wave period (T_z) visually observed and computed from measured data and the surf zone width are shown in Figure 3. The data shows that the visually observed wave height was 80% of the wave height computed from measured data. The width of the surfzone was more (> 15 m) during June to September and it was relatively narrow (< 15 m) during rest of the year.

Longshore Currents

The daily variation of longshore current estimated based on Longuet-Higgins equation considering the first breaker angle ($V_{L\text{-}H1}$), second breaker angle ($V_{L\text{-}H2}$) and the resultant ($V_{L\text{-}H}$) are shown in Figure 4 (A). The longshore current towards southwest was taken positive and that towards northeast was taken negative. It shows that the longshore current velocity estimated based on second breaker angle is 1.2 times that based on first breaker angle. The daily vari-

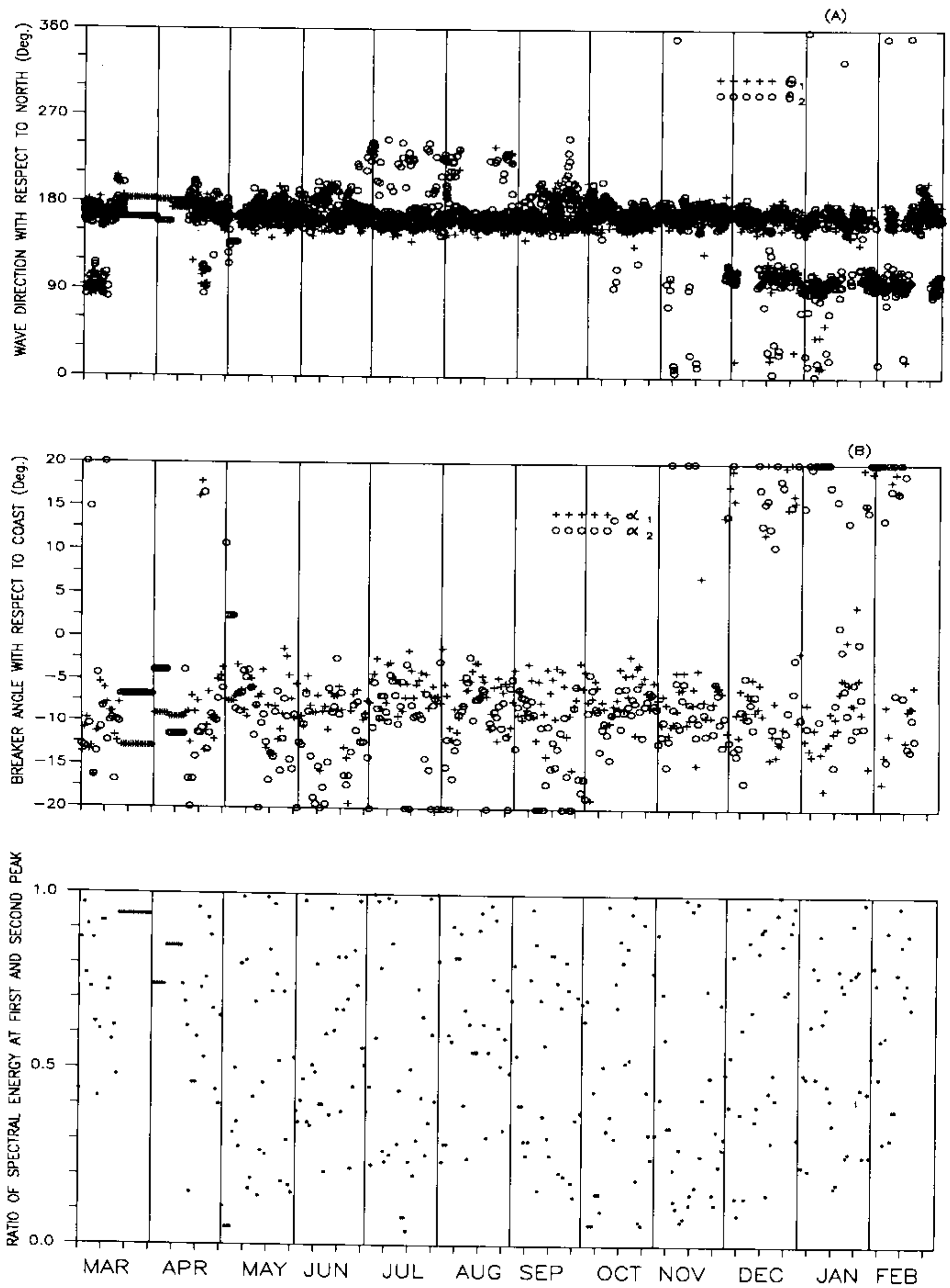

Figure 2. Variation of (A) wave direction at first and second peak (B) breaker angle at first and second peak and (C) ratio of spectral energy at first and second peak.

ation of longshore current estimated based on Galvin's equation considering the first breaker angle (V_{G1}), second breaker angle (V_{G2}) and the resultant (V_G) are shown in Figure 4 (B). It shows that longshore current velocity estimated based on second breaker angle is 1.15 times that based on first breaker angle. So it is important to consider the first and second breaker angle in estimation of longshore current. The variation of measured (V_M) and computed longshore current velocity is shown in Figure 4(C). The measured longshore current was northeasterly during March to October, and southwesterly from November to February. Strong longshore currents (> 0.5 m/s) were noticed in June, July and September. Longshore current was relatively weaker (< 0.5 m/s) during rest of the year. The comparison

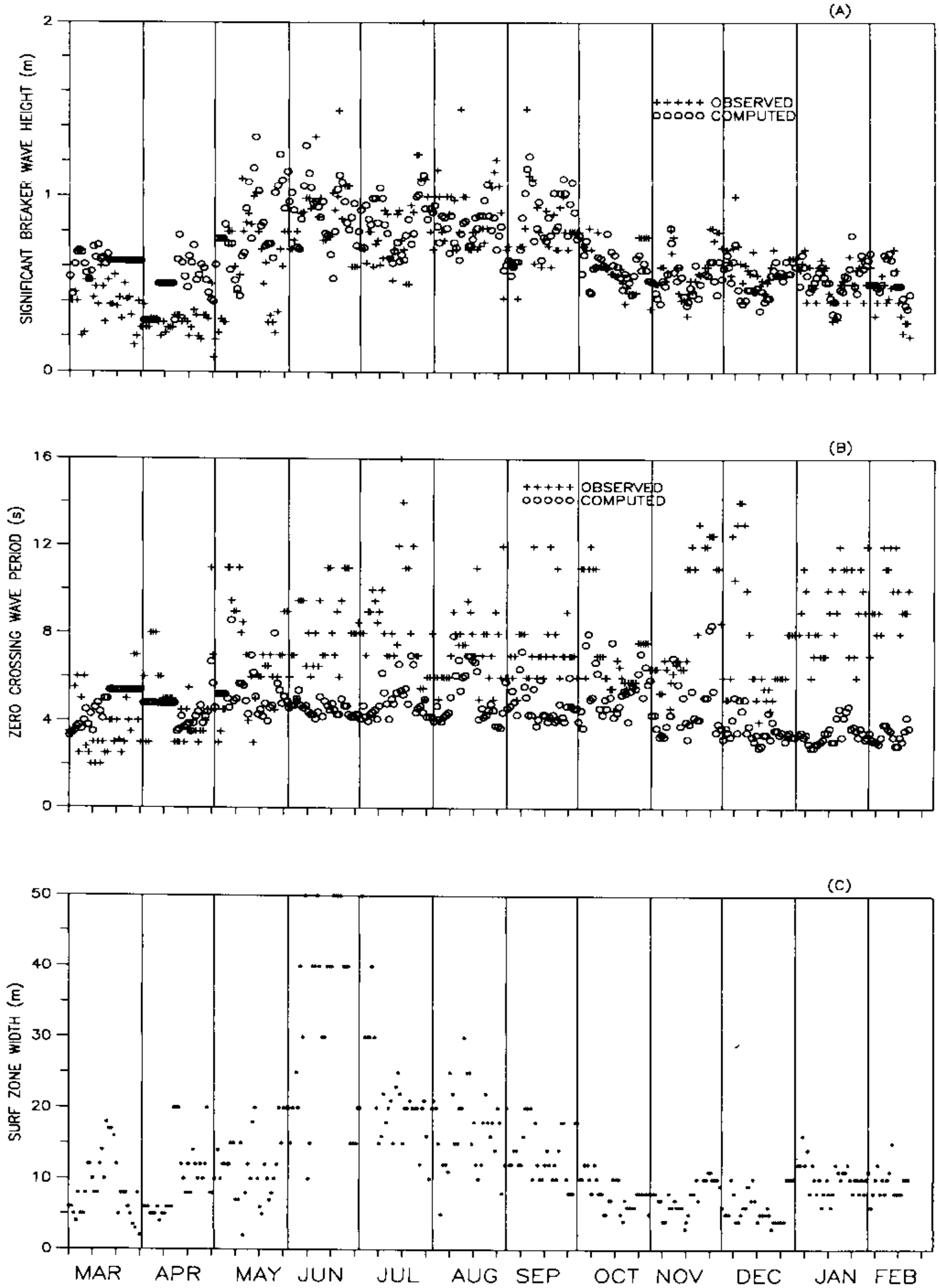

Figure 3. Variation of (A) observed and computed significant breaker wave height (B) zero crossing period and (C) surf zone width.

of the measured and computed longshore current velocity is shown in Figure 5. The figure shows that longshore current estimated based on Longuet-Higgins overpredicts that based on Galvin. The current speed computed based on Longuet-Higgins was about 32% more than the measured speed. The current speed computed based on Galvin was only about 6.5% more than measured speed. So it shows that the longshore current can be reasonably well estimated based on Galvin's equation for this region. It has to be noted that the longshore current magnitude and direction will considerably change with tidal phase.

Longshore Sediment Transport

The average coastal orientation of this coast is N54°E (*i.e.,* 54° clockwise to North). The 3-hourly measured wave charac-

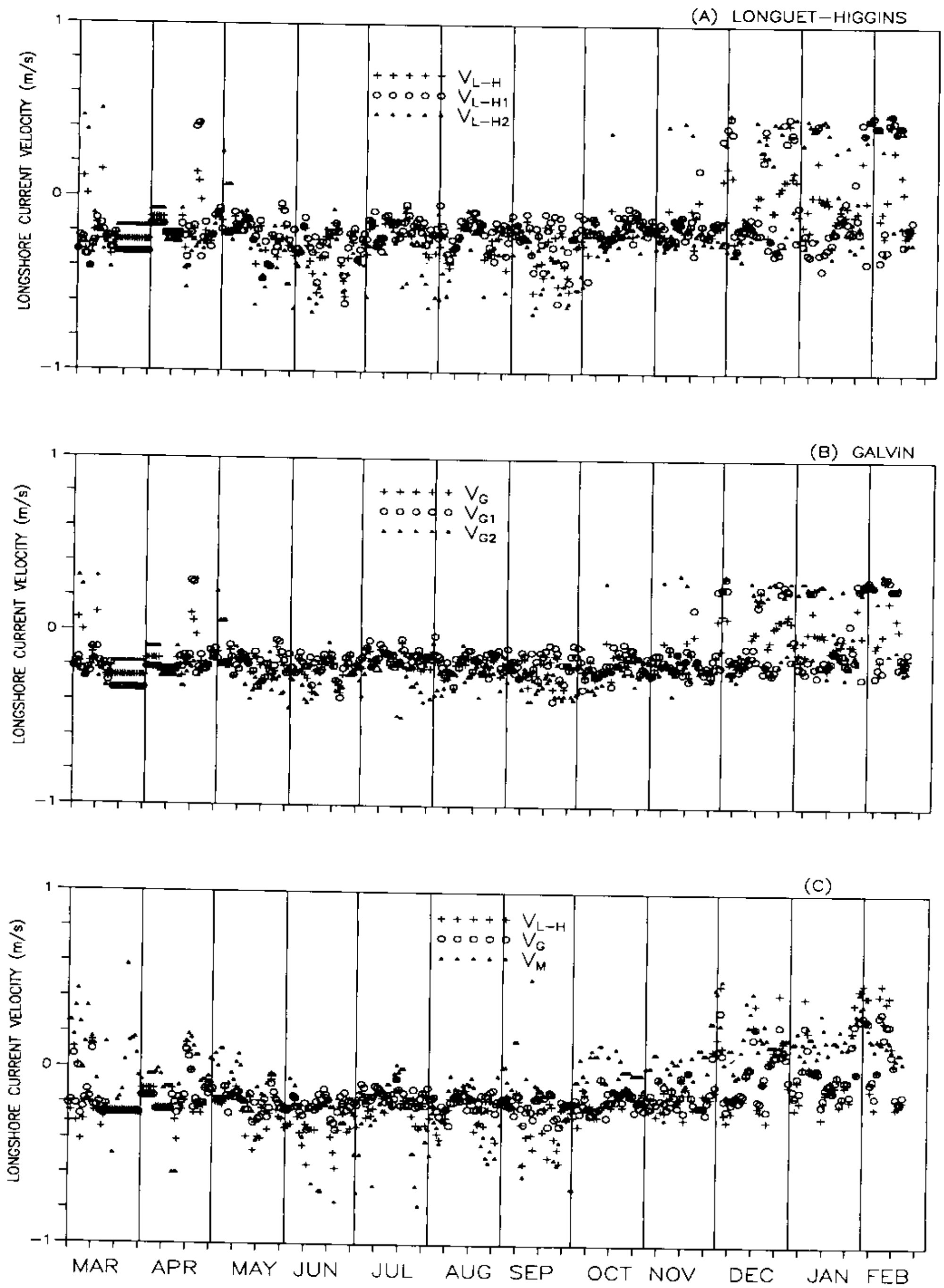

Figure 4. Variation of longshore current velocity (A) computed based on Longuet-Higgins (B) computed based on Galvin and (C) measured alongwith computed based on Longuet-Higgins and Galvin.

teristics reduced to breaker zone were used in eqn. (3) and the estimated monthly transport is presented in Table 3. It shows the sediment transport estimated based on first breaker angle, second breaker angle and the resultant. The annual net and gross sediment transport estimated based on second breaker angle was marginally more than that based on first breaker angle. The resultant sediment transport estimated shows that the transport rate was on the higher side around 0.095×10^6 m^3/month in June, 0.079×10^6 m^3/month in September and 0.071×10^6 m^3/month in May. It was low showing less than 0.005×10^6 m^3/month in December to February. The monthly distribution of littoral transport rate indicates that southwest monsoon waves show more significance compared to the northeast monsoon waves. The predominant direction of transport

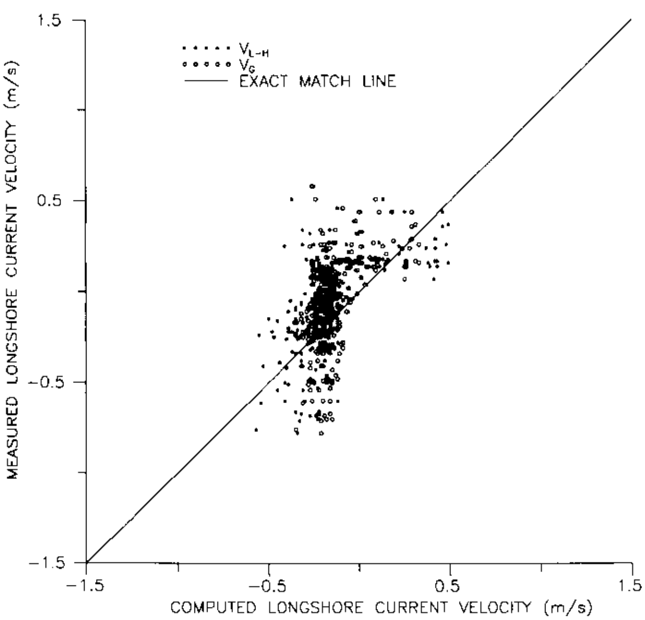

Figure 5. Comparison of measured and computed longshore current.

was northeasterly from March to November and southwesterly from December to February. The annual gross transport was found to be 0.46 × 10^6 m^3/year and the annual net transport was 0.44 × 10^6 m^3/year (towards northeast).

The average longshore current measured in the surfzone was used to estimate the sediment transport using Walton's equation and is presented in Table 4. The transport rate was on the higher side around 0.056 × 10^6 m^3/month in June, 0.030 × 10^6 m^3/month in July and 0.022 × 10^6 m^3/month in August. It was low showing less than 0.005 × 10^6 m^3/month in October to April. The predominant direction of transport was northeasterly from March to October and southwesterly from November to February. The annual gross transport was found to be 0.15 × 10^6 m^3/year and the annual net transport was 0.12 × 10^6 m^3/year (towards northeast).

Table 4. *Estimated longshore sediment transport in 10^6 m^3 based on observed data at Kannirajapuram.*

Month	Northeasterly	Southwesterly	Monthly Net*
Mar 97	0.000060	0.002294	−0.000166
Apr 97	0.002712	0.000469	−0.002243
May 97	0.006415	0.000433	−0.005981
Jun 97	0.055929	0.000000	−0.055929
Jul 97	0.030303	0.000048	−0.030255
Aug 97	0.021686	0.000000	−0.021686
Sep 97	0.015666	0.002090	−0.013576
Oct 97	0.002647	0.000771	−0.001877
Nov 97	0.000602	0.002247	0.001644
Dec 97	0.000222	0.003712	0.003490
Jan 98	0.000072	0.005245	0.005173
Feb 98	0.000000	0.003959	0.003959

Annual net sediment transport = −0.117447 × 10^6 m^3/year.
Annual gross sediment transport = 0.145979 × 10^6 m^3/year.
* (−) northeasterly transport (+) southwesterly transport

The difference between the sediment transport estimated based on the above two methods are due to the fact that eqn. (3) is based on the assumption of long and open beach with adequate sand supply. The beach considered under study is 13 km long with Rivers Vaippar joins Gulf of Mannar on the southern side and River Gundar joins the Gulf on the northern side. So considering the coastal topography the sediment transport estimated based on eqn. (3) has certain limitations as mentioned above when applied to this coast. Under such conditions a realistic estimation can be made based on Walton's equation which consider the measured longshore current.

The earlier study (CHANDRAMOHAN *et al.* 1990) shows that estimated longshore sediment transport based on the ship reported wave data for Tuticorin which is 50 km south of Kannirajapuram was 0.33 × 10^6 m^3/year towards the southwest and it was 0.33 × 10^6 m^3/year towards the northwest indicating that Tuticorin region is nodal drift point. The present study based on measured wave data and longshore current shows that Kannirajapuram coast is not a nodal drift point having a net transport of 0.12 × 10^6 m^3/year towards northeast. The difference is due to the coastal orientation at

Table 3. *Estimated longshore sediment transport in 10^6 m^3 based on measured wave data.*

	Based on First Breaker Angle			Based on Second Breaker Angle			Resultant		
Month	NE	SW	Net*	NE	SW	Net*	NE	SW	Net*
Mar 97	0.034249	0.02755	−0.031494	0.023471	0.002435	−0.021037	0.028332	0.001708	−0.026624
Apr 97	0.018770	0.001171	−0.017599	0.023374	0.000000	−0.023374	0.019850	0.000330	−0.019520
May 97	0.064553	0.000000	−0.064553	0.085237	0.001300	−0.083937	0.071203	0.000000	−0.071203
Jun 97	0.086078	0.000000	0.086078	0.111381	0.000000	−0.111381	0.094901	0.000000	−0.094901
Jul 97	0.049426	0.000000	−0.049426	0.077222	0.000000	−0.077222	0.057440	0.000000	−0.057440
Aug 97	0.049135	0.000000	−0.049135	0.065087	0.000000	−0.065087	0.054245	0.000000	−0.054245
Sep 97	0.071868	0.000000	−0.071868	0.094236	0.000000	−0.094236	0.078663	0.000000	−0.078663
Oct 97	0.026822	0.000000	−0.026822	0.033112	0.000000	−0.033112	0.028073	0.000000	−0.028073
Nov 97	0.016011	0.000820	−0.015191	0.015385	0.001687	−0.013698	0.015608	0.000655	−0.014954
Dec 97	0.009164	0.010592	0.001428	0.006352	0.009137	0.002785	0.006778	0.007855	0.001078
Jan 98	0.009553	0.009393	−0.000160	0.002941	0.017986	0.015045	0.004195	0.009186	0.004991
Feb 98	0.011590	0.015243	0.003653	0.011591	0.014539	0.002948	0.010894	0.014418	0.003524

Annual net transport −0.407245 × 10^6 m^3/year −0.502305 × 10^6 m^3/year −0.436031 × 10^6 m^3/year.
Annual gross transport 0.417406 × 10^6 m^3/year 0.543862 × 10^6 m^3/year 0.455216 × 10^6 m^3/year.
* (−) northeasterly transport (NE) (+) southwesterly transport (SW)

Tuticorin and Kannirajapuram and the assumption of long and open beach with adequate sand supply and the use of deep water ship reported data in the earlier study.

CONCLUSIONS

The measured wave data shows that highest significant wave height was 1.93 m in May 1997 and the highest maximum wave height was 2.96 m was in September 1997. The ratio of spectral energy at first and second spectral peak shows that energy at second peak was more than 50% of energy at first peak in 57% of the data collected. So it is important to consider the both directions for this location. The longshore current speed computed based on Longuet-Higgins was about 32% more than the measured speed. The current speed computed based on Galvin was about 6.5% more than measured speed. So it shows that the longshore current can be reasonably well estimated based on Galvin's equation for this region. The annual net and gross sediment transport estimated based on second breaker angle was marginally more than that based on first breaker angle. The sediment transport estimated based on Walton's equation can be considered more realistic for this coast. The sediment transport using Walton's equation shows that annual gross transport was 0.15×10^6 m^3/year and the annual net transport was 0.12×10^6 m^3/year (towards northeast).

The study shows that field measurements are very important. Theoretical approach without field measurements would lead to wrong assessment of the magnitude and direction of the longshore current as well as the longshore sediment transport.

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